Simulation of East Asian Summer Monsoon with IAP CGCM

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ABSTRACT

East Asian summer monsoon simulated by a coupled ocean–atmosphere general circulation model developed in the Institute of Atmospheric Physics (IAP CGCM) is analyzed. The precipitation, low–level streamline field, sea level pressure, low–level temperature and mixing ratio are compared with the observed ones respectively.

The results show that IAP CGCM can simulate most features of summer monsoon circulation, but it still has some important systematic errors. The simulated Somali jet tends to be much weak and lies too far south. The cross–equatorial flows between 120°E and dateline are also too weaker in the model than those in reality, while the South Asia monsoon low is stronger than that in the observation and reaches further east. At the same time, the subtropical high in the western Pacific extends too far west and north. Accompanied by these deviations in tropical and subtropical zones, the westerly troughs in the middle and high latitudes affect further southerly regions in China than those observed. All these deficiencies in simulating summer monsoon circulation result in the errors in modelled precipitation in East Asia, which include the underestimation of precipitation over East Asia in summer, the premature emergence of maximum precipitation and the further southerly rainfall belt in East Asia than the observed one. So the most obvious drawbeck of the model is the apparent underestimation of Meiyu frontal rainfall.

Key words: East Asian summer monsoon, Coupled ocean–atmosphere model

I. INTRODUCTION

Asia is a significant monsoon region where the drought and flood in summer and cool injury in winter are mainly determined by the activities of summer and winter monsoon. So the prediction for interannual variability of monsoon in Asia is very important and the simulation of Asian monsoon, especially the summer monsoon has become a critical test of model's ability.

Asian summer monsoon is composed of two components––Indian and East Asian summer monsoon. The previous studies with models have been mainly concentrated on the former. For example, there are 30 Atmospheric General Circulation Models (AGCMs) taking part in AMIP (Atmospheric Model Intercomparison Project) to simulate the Indian summer monsoon (Wang, 1994). However, there are some works which have been devoted to the latter (Zeng et al., 1988; Yuan, 1990; Shukla et al. 1992; Sperber et al., 1994; Latif et al., 1994; Wang et al., 1996). These efforts for simulating monsoon show that the most of models can simulate some features of summer monsoon in Asia to some extent, but they still have some important deficiencies.

Chinese meteorologists have studied East Asian summer monsoon for a long time and

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have achieved a lot of significant theoretical fruits, especially in 1980s. The most important findings include that East Asian monsoon circulation system is independent of Indian summer monsoon circulation system due to the different relative position of ocean and land and the effect of Qinghai–Xizang Plateau, it is more complex than the latter in structure and circulation system. Zhu et al. (1985) further pointed out that the East Asian summer monsoon is composed of two different monsoons: tropical and subtropical monsoons. In recent years, more and better observational data and more numerical experiments have produced more up–to–date fruits in the large–scale circulation and circulation systems, the mechanisms of establishment and maintenance of monsoon in East Asia, and so on (Chen et al., 1991). These fruits provide more background knowledge for analyzing the simulation with numerical models.

The major purpose of this paper is to test the ability of a coupled general circulation model (CGCM) to simulate East Asian summer precipitation and summer monsoon circulation, and to investigate the basic origins for simulated errors preliminarily. It should provide the basis for improving the model in the future.

II. MODEL AND DATA

A coupled ocean–atmosphere general circulation model has been developed in the Institute of Atmospheric Physics (IAP CGCM). The atmospheric and oceanic components have same horizontal resolutions: 4° in latitude and 5° in longitude, but different vertical resolutions: two layers for AGCM and twenty layers for OGCM. At air–sea interface, a method similar to flux correction is applied, i.e., only the anomalous flux relative to that in uncoupled model climate is exchanged in order to control initial climate drift resulting from the inconsistency of surface flux of the uncoupled AGCM and OGCM. The time step for coupling is one month. The coupled model has been integrated for 130 years and the global mean sea surface temperature drifts about 2°C toward cold direction (Chen, 1994). The global mean climate characteristics and annual variability simulated by IAP CGCM have been compared with the observation, and the results are encouraging (Chen, 1994; Yu et al., 1994; Guo et al., 1996).

In this paper, the data of model are derived from the 130–year integration results above; while the observed data are from the climatological charts given by Ding (1987) and Dong (1990) and from Internet.

III. SIMULATION OF PRECIPITATION IN EAST ASIA

1. *Regional Mean*

In this paper, East Asia is referred to the area between 70°E and 140°E and between 10°N and 60°N. The averaged precipitation over East Asia simulated by IAP CGCM can reflect the basic seasonal cycle of the observation (Figure 1), but the rainfall amount in summer is obviously underestimated and the maximum precipitation appears in July, which is in fact in August in the observation.

2. *Spatial Pattern*

Figure 2 shows the spatial distribution of summer precipitation in East Asia based on the data from Internet, together with the model simulation. The feature in observed precipitation

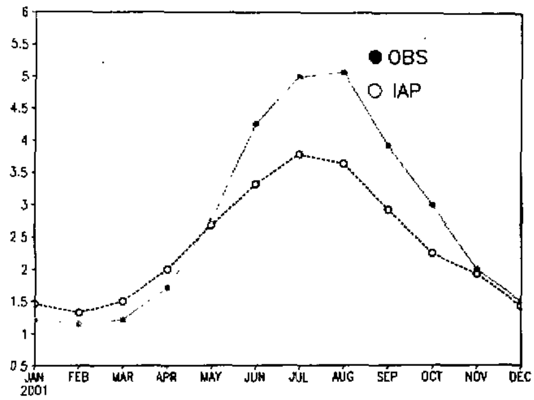

Fig. 1. The annual cycle of precipitation (mm / day) averaged over East Asia from observed and IAP CGCM.

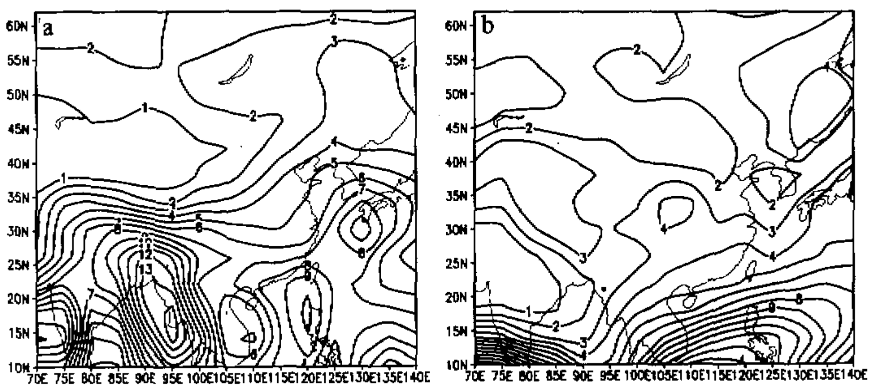

Fig. 2. The seasonal mean precipitation (mm / day) in summer in East Asia from observed (a) and IAP CGCM (b).

is dominated by 2 main precipitation regions in South Asia and East Asia, with a rather dry region in Northwest China.

The main centers of precipitation in IAP CGCM lie too far south, which leads to very small rainfall amounts in areas including East China, Korea peninsula and southern Japan and too much precipitation in regions close to the Philippines. In the contrast, there is a false high precipitation simulated by the model in Northwest China.

3. *Evolution of Precipitation*

In order to investigate further the evolution of precipitation, we examined maps of precipitation for the months from March to September simulated by IAP CGCM in Figure 3.

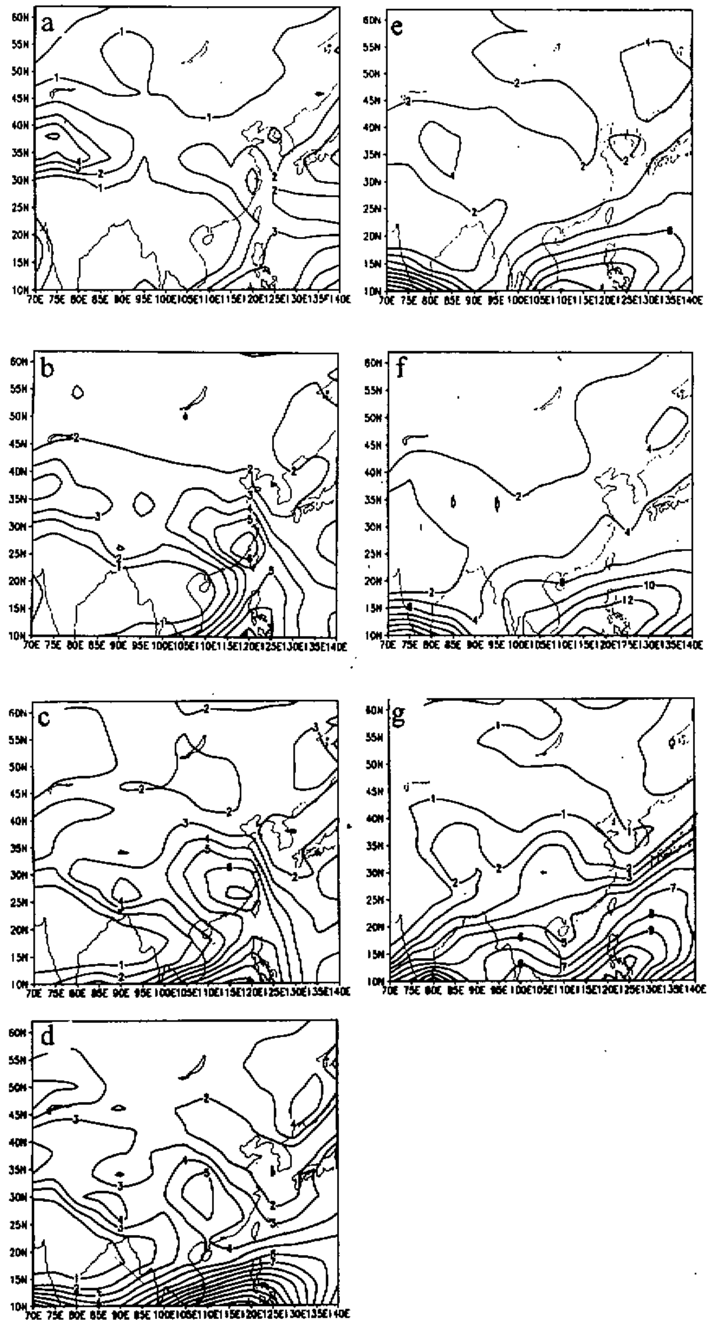

Fig. 3. the time evolution of precipitation (mm / day) in East Asia from IAP CGCM. (a) March (b) April (c) May (d) June (e) July (f) August (g) September.

The observation indicates that main rainfall belt stays three times and shifts northward twice northward shift and twice with the abrupt northward jump of subtropical high in the western Pacific. The rainfall in South China is always increasing from March to May, which reaches its maximum in May and is called "preflood season " precipitation. The main precipitation belt reaches to the Yangtze Valley in June, and then in Northeast and North China in July, at last it retreats southward obviously in September.

IAP CGCM generally can simulate the so-called "preflood season" rainfall in South China, though the intensity and position of the center in the model are not in good agreement with the observation. However, the precipitation belt does not shift northward in June and July, so the rainfall amounts in the east of China reduce obviously in these two months compared to the earlier month. We can find that the rainfall in East China, Korea peninsula and southern Japan is remarkably underestimated from June to September.

IV. SIMULATION OF SUMMER MONSOON CIRCULATION

Why is the simulated precipitation in summer in East Asia not satisfactory? This is a question that we try to answer in this part. Because summer monsoon circulation has close relationship with the rainfall in summer, the summer monsoon circulation simulated by IAP CGCM will be analyzed here.

At first, it should be pointed out that because of the rather low vertical resolution of the AGCM (with the top of the model being at 200 hPa), only the low-level monsoon circulation simulated by IAP CGCM can be analyzed, it is impossible for the model to correctly simulate the upper-level monsoon circulation system members, which is also one of the important factors that contribute to the errors in precipitation in IAP CGCM.

1. *Low-level Streamline Field*

Figure 4 illustrates the observed and simulated streamline fields at 1000 hPa. The observational map is characterized by 4 main cross-equatorial flows, with the strongest one close to Somali jet, and the other three weaker ones in 105–110°E, 120–125°E and 150°E respectively. There are three branches of summer monsoon influencing China, one of which is Indian monsoon that mainly affects Southwest China, the other two are from cross-equatorial flow over the South China Sea and from the western part of subtropical high in the western Pacific which has close relationship with the precipitation in the central and eastern parts of China.

Compared with the observed ones, there are considerable errors in the simulated Asian summer monsoon circulation. Especially, the Somali jet is weaker and has further south position, which can be found more distinctly in 850 hPa streamline field (not shown). In addition, the cross-equatorial flows between 120°E and dateline area also weaker than those in the observation. These errors make the mian confluence of southwest flow appear in the region close to the Philippines that is in consistent with the major rainfall region simulated by IAP CGCM. At the same time, the simulated subtropical high in the western Pacific extends too far west and north, which results in that the eastern parts of China, Korea peninsula and southern Japan are chiefly influenced by southeast flows that different from the southwest flows in reality, together with the more prevalent northerly flow in the northern parts of China in model than in the observation.

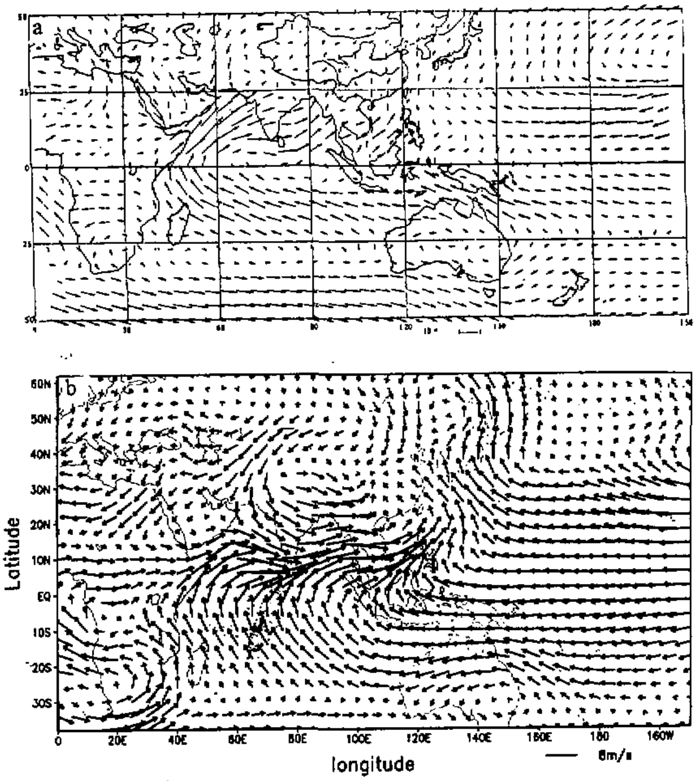

Fig. 4. The 1000 hPa wind field (m / s) in Asian summer monsoon region from observed (a), IAP (b).

2. *Sea Level Pressure*

The observation suggests that there are four main pressure systems in Asian monsoon region, which include South Asia monsoon low, subtropical high in the western Pacific, Australia cold high and Marquesas cold high in the Southern Hemisphere. The following will focus on the evolution of these four pressure systems in the observed and simulated sea level pressure to find the effect of errors in simulating them on the simulation of precipitation in the model.

In the observed data, South Asia monsoon low establishes in May with its center being in the northern India. It continuously strengthens in June and July, and then weakens in August and September. To the east, the ridge of subtropical high in the western Pacific stays to the south of 20°N before May, then it shifts northward to the north of 20°N and 25°N in June and July respectively and weakens obviously in September. In the Southern Hemisphere, two cold highs establish in June and strengthen in July, then begin to weaken in August (figure not

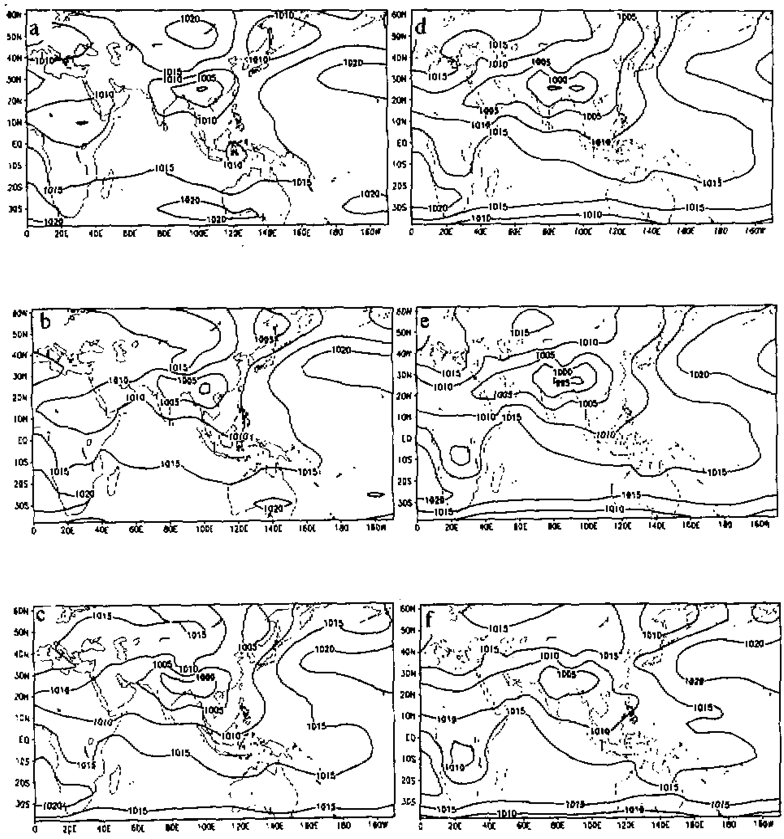

Fig. 5. The sea level pressure field (hPa) from IAP CGCM. (a) April (b) May (c) June (d) July (e) August (f) September.

shown).

In the model, South Asia monsoon low has already been strong in April with a false center located in the northern southeast Asia, and it is always stronger than the observed with its position further to the east of the observation in the period from May to August (except June); while the simulated ridge of subtropical high is always staying to the north of 25°N, and its affecting region is more westerly than the real situation. Moreover, the subtropical ridge does not shift northward in June and July, which is in agreement with the evolution of rainfall belt in the model. So the dissatisfaction with the model to simulate subtropical high is a direct factor that causes the failure of simulating summer precipitation in East Asia. We can also notice that the model cannot simulate two cold highs in the Southern Hemisphere from June to August. However, the researches on these two cold highs illustrate that they are critical to form the cross-equatorial flows between 120°E and dateline. Therefore all main pressure system components in Asian monsoon region in the model need improving.

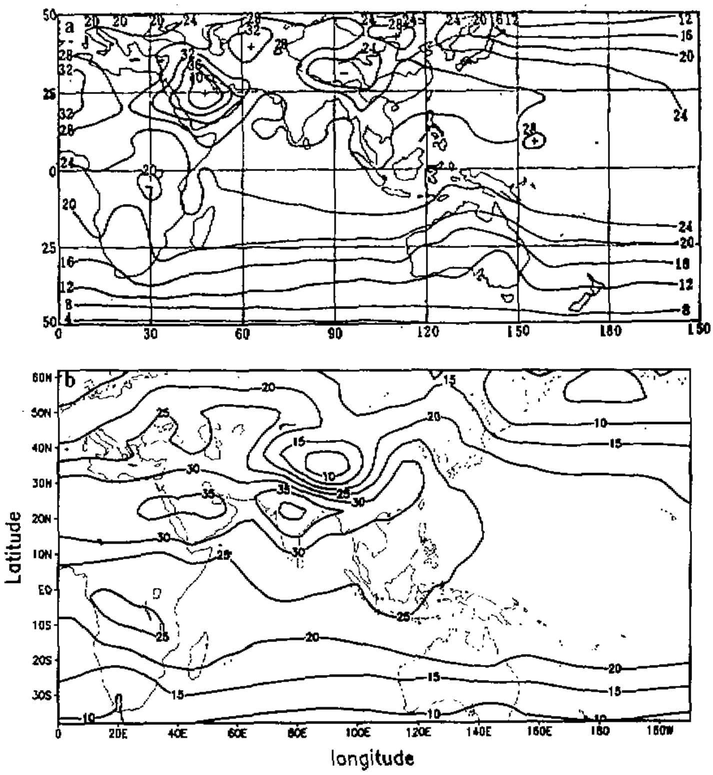

Fig. 6. The temperature (°C) in Asian summer monsoon region in summer season from observed (1000 hPa) (a), IAP CGCM (surface) (b).

3. *Low–level Temperature*

It is well known that thermodynamic difference between ocean and land is the most essential factor that forms and keeps monsoon, so it is important to investigate the ability of the model to simulate features of temperature, especially at low level.

The major features in the observed temperature at 1000 hPa in Asian monsoon region are involved in the warm center in Arabian peninsula and cold center in Qinghai–Xizang Plateau, as well as a vast warm region covering India and Southeast Asia (Figure 6a).

The simulated warm center in Arabian peninsula is weaker than the observed (Figure 6b), which leads to the weaker temperature difference between ocean and land and weaker Somali jet in IAP CGCM. In contrast, the cold center in the Plateau is stronger than the observed. There is a false warm center in India simulated by IAP CGCM, which causes the simulated South Asia monsoon low to be stronger and in the further east position of that in the observation. In the Southern Hemisphere, the model cannot simulate temperature troughs connecting to the missing of two cold highs in IAP CGCM. So in order to simulate monsoon precipitation better, the low–level temperature in the model also needs to be further improved.

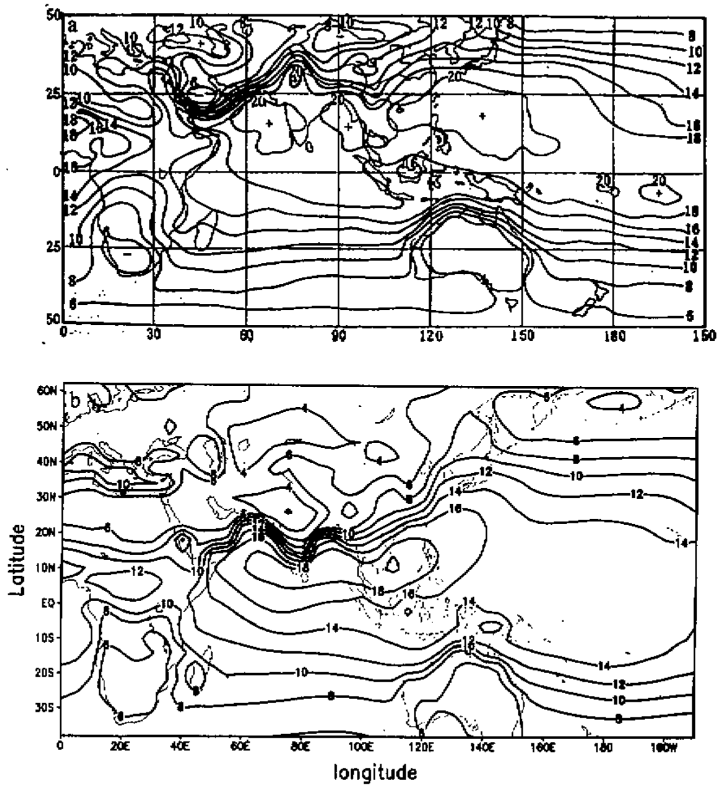

Fig. 7. As in Fig. 6, except for mixing ratio (g / kg).

4. *Low–level Mixing Ratio*

In order to test the sources of vapor for East Asian summer monsoon precipitation simulated by the model, the mixing ratio from the model in Asian monsoon region is compared with that observed. Three wet centers can be found from the observational mixing ratio shown in Fig. 7a, and they situate in the Arabian Sea, the Bay of Bengal and the western Pacific including the South China Sea, respectively. The wet center in the Bay of Bengal has an important impact on the precipitation in Southwest China, while that in regions from the South China Sea to the western Pacific is major sources of vapor to the eastern parts of China. It also should be pointed out that there is a dry center in Xinjiang region and the western Mongolia in observed mixing ratio data.

IAP CGCM simulates an integrated wet region in tropical oceans instead of three isolated wet centers (Fig. 7b). Meanwhile, the simulated high mixing ratio and strong gradient regions are weaker and have further south position than the observation, which is consistent with the errors of southwest flow and precipitation in East Asia simulated by IAP CGCM, so it is connected with the further south monsoon rainfall belt. While the wet tongue in the southern Xinjiang and the northern Plateau does not appear in the observation, it is consistent with the false high precipitation in this regioin in the model.

V. DISCUSSION

Tao et al. (1987) published the illustration of East Asian monsoon circulation system. At low–level, the East Asian monsoon system includes Australia cold high, cross–equatorial flows, subtropical high in the western Pacific, westerly trough in middle and high latitudes and two rainfall belts that correspond to ITCZ and Meiyu frontal convergence belt respectively. These system components are interrelated each other and the variation in each component can affect all other components.

Compared with the observation, we find that IAP CGCM can't simulate Australia cold high, which causes the equatorial flows between 120°E and dateline to be weaker than that in the observation. Meanwhile, the Somali jet is weaker and has further south position. While the subtropical high in the western Pacific extends too far west and north, South Asia monsoon low is stronger and has further east position. In addition, the westerly trough is also stronger and affects further southerly regions in China than the observed one. All the errors in simulating monsoon circulation make the southwest monsoon confluent in the vicinity of Philippines, which lead to too much precipitation in the model than in the observation in this region, while there are less southwest and more southeast flows influencing the eastern parts of China, Korea and southern Japan, which leads to less precipitation in these regions in the simulation than in reality. As a result, the major simulated centers of precipitation in East Asia are weaker and have further south position than the observed.

These errors in simulated monsoon circulation have their basic origin in the simulation of low–level temperature that does not reflect well the essential thermodynamic difference between ocean and land. This may be resulting from the low vertical resolutions and not including land processes accurately. However, some works show that changing the albedo in the Qinghai–Xizang Plateau to the corresponding climatological value or adding the land processes into the model can improve the simulation of low–level temperature and bring better simulation of evolution of precipitation in East Asia (Lin, 1995; Dai, 1995), although there are still some problems.

Besides the land processes, sea surface temperature (SST) also plays an important impact on the simulation of East Asia summer monsoon. As described in the Section II, there is cold trend in the extended integration of the model, the global mean SST is 2°C lower than the observed one. In another sensitivity experiment with the same model, in which the atmospheric carbon dioxide concentration is doubled, the simulated global mean SST is close to the observed one. Chen (1996) analyzed precipitation from the two experiments above and found that the simulated monsoon precipitation in the sensitivity experiment is more realistic. So the poor simulation of SST may be one of the causes that result in weaker monsoon precipitation in East Asia.

Both two reasons above are related to large scale circulation patterns, but the simulation of precipitation is still closely associated with cumulus convection parameterization. Because there are only two layers in the atmospheric component of the coupled model, it is almost impossible to do a reasonable convective parameterization and produce a realistic precipitation pattern in this model. Although we can not analyze effects of convective parameterization on the precipitation in detail, it is expected that it may also play an important impact.

VI. CONCLUSION

By the analyses of precipitation and monsoon circulation in East Asian monsoon region simulated by IAP CGCM, the major conclusions can be attained as follows:

IAP CGCM can reproduce the basic features of seasonal cycle of averaged precipitation over East Asia, but the simulated mean precipitation in summer is less than the observation and the maximum appears a month earlier. As for the spatial distribution, there are also some obvious drawbacks such as the further south position of the precipitation belt and the apparently weaker Meiyu frontal rainfall.

Compared with the observed ones, though most characteristics of summer monsoon circulation can be simulated by IAP CGCM, there are still considerable errors in the simulating components of Asian summer monsoon system that have close connection with errors in precipitation in East Asia in the model. In order to get better simulation of precipitation in East Asia, the land processes, SST simulation and cumulus convective parameterization need to be improved further.

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